DOI: https://doi.org/10.24425/amm.2023.146231

N.F. YAHYA[1*], T.N.H.T. ISMAIL[1], F.M. YUSOP[1], N.A.A.M. MAHANI[1],
A.F. MALIK[1], L.A. SOFRI[2], J. GONDRO[3]

A REVIEW OF TENSILE PROPERTIES OF NATURAL FIBRES FOR GEOTECHNICAL APPLICATIONS

Natural fibres have recently gained attention as an alternative sustainable material for civil engineering applications due to natural fibres' exceptional performance, including high strength, and their environmental-friendliness and cost-effectiveness. However, there are disadvantages to using natural fibres in extreme environments. Therefore, this paper reviewed the effect of moisture content and temperature on the tensile strength of potential natural fibres for engineering purposes. Furthermore, this paper also critically reviewed the influence of alkaline treatment on natural fibres' tensile strength. This is significant because alkaline treatment enhances surface friction and the fraction of the revealed cellulose on the fibres' surface, resulting in better mechanical interlocking. In conclusion, natural fibres demonstrate their potential for geotechnical applications due to the materials' strong tensile properties after being subjected to treatment processes.

Keywords: Natural fibres; tensile strength; geotechnical applications

1. Introduction

Soil is one of the most critical and elemental media used in construction projects throughout the world [1]. All the loads attained on structures are carried directly to the ground. If the underlying soil is not stable enough to carry transferred loads, failures, such as structure settlement, cracks, and so on, can occur [2,3]. In reinforced soil, soil mass is improved by inserting tensile-resistant reinforcement. If the soil contains discrete elements for improving its qualities by randomly distributing specified-length fibres, it is referred to as fibre-reinforced soil. Soil reinforcement is a method of enhancing soil qualities through chemical or mechanical techniques, with the primary goals of increasing strength and reducing settlement and lateral deformations [4]. Soil reinforcement with fibres is a composite material in which high-tensile-strength fibres are placed within the soil matrix. When the composite is put through shear stresses, the fibres' tensile resistance is mobilised, and tensile resistance from the fibres confers additional strength to the soil [5]. Natural fibres are now widely employed in synthetic fibres, with environmentally benign, biodegradable, and other unique characteristics [6].

Therefore, natural fibres provide the enhancement of mechanical properties in soil. Natural fibres are among agricultural wastes with significant advantages of high strength [7,8], less abrasiveness [9], cost-efficient [7], lightweight [9], biodegradability [10], and being eco-friendly [11]. Natural fibres can be obtained abundantly from many types of plants, such as bamboo [12,13], kenaf [14], sisal [4,15], jute [15], and banana [16]. Waste generation at the global level is expected to increase by 70% in 2050. Nearly eight billion individuals are responsible for generating 2.5 billion tonnes of waste a year. Agricultural waste is one of these types of massively disposed solid waste. Over 90% of waste in developing and low-income nations are thrown in open fields, resulting in major health and environmental implications [17].

However, when a product with natural fibres reaches the end of its life cycle, it is disposed of and composted without affecting the environment. Natural fibres outperform wood fibres in terms of physical and mechanical features; they also have a high cellulose content and crystallinity and lighter weight. These characteristics attract more recognition from industries nowadays [11]. Moisture content, alkaline treatment, temperature, and fibre density have significant impacts on the properties of natural fibres, especially tensile strength, dimensional stability, and swelling behaviour, and hence the study of these factors is important for engineering purposes [18,19].

[1] UNIVERSITI TUN HUSSEIN ONN MALAYSIA, FACULTY OF ENGINEERING TECHNOLOGY, 84600 PANCHOR, JOHOR, MALAYSIA
[2] UNIVERSITI MALAYSIA PERLIS (UNIMAP), CENTRE OF EXCELLENCE GEOPOLYMER & GREEN TECHNOLOGY (CEGEOGTECH), 01000 PERLIS, MALAYSIA
[3] CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF PRODUCTION ENGINEERING AND MATERIALS TECHNOLOGY, DEPARTMENT OF PHYSICS, 19 ARMII KRAJOWEJ AV., 42-200 CZĘSTOCHOWA, POLAND

* Corresponding author: nurfaezah@uthm.edu.my

2. Potential natural fibres for geotechnical applications

In recent decades, there has been a growing emphasis on utilizing renewable raw resources to create sustainable products in order to reduce the reliance on fossil fuels and to reduce environmental degradation [20]. Due to their abundance in nature, natural fibres have become an effective alternative to current fibres as raw materials. Natural fibres have a lot of potential for geotechnical applications and have gotten a lot of attention lately because of their mechanical strength properties. Based on the literature, TABLE 1 shows the details of the chemical properties of various natural fibres.

TABLE 1

Chemical Properties of Natural Fibres

Type of fibre	Cellulose (%)	Lignin (%)	Hemicellulose (%)	References
Bamboo	73.83	10.15	12.49	[21]
Kenaf	66.47	2.39	9.43	[22]
Sisal	65-68	9.9-14	10-22	[23]
Jute	64.4	11.8	12	[24]
Banana	63-64	5.0	19	[25]
Hemp	70.2-74.4	3.7-5.7	17.9-22.4	[26]
Agave	68.42	4.85	4.85	[26]
Cotton	85-90	7-16	1-3	[27]

Cellulose, hemicellulose, and lignin are the main components of natural fibres' cell walls [26,28] and the chemical properties of natural fibres may be found within certain ranges. Cellulose ranged from 63% to 90% of the entire chemical properties of natural fibres. From the table, banana fibres had the least cellulose of 63%, while cotton fibres had the maximum cellulose of 90%. Lignin ranged from 2.39% to 16%, where the minimum of 2.39% existed in kenaf fibres and the maximum lignin of 16% was observed in cotton fibres. Hemicellulose ranged from 1% to 22.4%. Cotton fibres had the minimum, while hemp had the maximum, of hemicellulose content. Chemical treatments using different chemicals can be used to remove cellulose, hemicellulose, and lignin from natural fibres. As determined by researchers, improvements in stiffness are attributed to the increased cellulose content in fibres and the decrease in composite porosity due to enhanced interface bonding between fibre polymers and matrix polymers [29].

Lignin is an unwanted polymer that requires a lot of energy and chemicals to remove during pulping. Lignin removal will remove celluloses and hydroxyl groups in natural fibres, improving their thermal stability and mechanical properties [30]. According to [31], hemicellulose removal via alkaline treatment resulted in increased viscosity of cellulosic solutions and improved the compactness and tensile strength of the regenerated fibres. The key to hemicellulose removal is removing branched hemicelluloses at lower alkali concentrations to preserve the unbranched hemicelluloses. Additional treatments have also been applied to ensure that natural fibres can be used as a component for geotechnical applications.

Due to its gelation capabilities, cellulose has several possible applications in geotechnical engineering. It can be used to make thickeners and stabilizing agents [32]. Soils with natural cellulose have much higher tensile and flexural strength [33]. In addition, cellulose has been employed to construct open-graded friction course (OGFC) pavement. OGFC comprises single-size coarse aggregates with wide voids, resulting in a high asphalt content, and cellulose helps it perform better by reducing coarse aggregate pop-out and reflective cracking [34]. Lignin is an excellent alternative to traditional stabilizers. Lignin connects soil particles and reduces large pores, generating a stable soil structure [35].

3. Effect of moisture content on tensile strength

The effect of moisture content on the mechanical properties of natural fibres is an important issue when employing natural fibres for geotechnical applications. Due to their hydroscopic nature, bamboo fibres tend to modify their mechanical characteristics depending on the amount of moisture present [36]. From [18], the moisture content has a considerable impact on the mechanical properties of fibres. Hence, their vulnerability to moisture content has limited natural fibres' application as reinforcements due to their chemical composition, which is rich in cellulose, and their hydrophilic nature.

Moisture content causes fibre swelling, which can degrade the mechanical and dimensional properties of composites. The swelling of fibres is attributed to the filling of the gaps between the fibres and the matrix, which is produced by the presence of moisture. However, moisture content may also result in the improvement in the mechanical properties of specific fibres [37]. It was discovered that the key components responsible for significant moisture absorption are cellulose and hemicellulose [38].

The results of natural fibre's tensile strength from moisture studies are shown in TABLE 2. Based on the findings, it can be concluded that moisture content played a substantial role in determining the mechanical properties of most of the fibres. The highest tensile strength was recorded for sisal fibres with 65%

TABLE 2

Effect of Moisture Content on Tensile Strength

Type of fibre	Moisture Content (%)	Tensile Strength (MPa)	Reference
Bamboo	15	232	[39]
	20	231	[39]
Kenaf	65	275	[40]
	90	430	[40]
Sisal	65	680	[40]
	90	250	[40]
Jute	65	430	[40]
	90	563	[40]
Banana	20	525	[40]
	40	540	[40]

moisture content, while the least was at 20% for bamboo fibres. However, the effect of moisture content on tensile strength was not statistically significant. The data may be affected by the different densities, lengths, and ages of the fibres.

4. Effect of alkaline treatment on tensile strength

Alkaline treatment is one of the variables that influence the mechanical properties of fibres. Natural fibres cannot be used in their natural state because of their hydrophilic character, which causes them to absorb water. However, their mechanical properties can be improved using the alkaline treatment [41], which results in surface alteration. An alkaline treatment usually removes lignin, hemicellulose, and other impurities in fibres [42]. Other than that, based on [43], the alkaline treatment considerably adjusts the structure of fibres to release the hydrogen connection, which increases the harshness of the surface of fibres.

The alkaline treatment enhances surface friction and the proportion of revealed cellulose on the fibres' surface, resulting in more excellent mechanical interlocking [44]. Thus, the alkaline treatment creates different mechanical locking sites, improving interfacial bonding and increasing fibre strength [45]. Alkaline treatments of natural fibres using sodium hydroxide (NaOH) were reviewed to validate the treatment's effectiveness in terms of optimal tensile strength.

Bamboo fibres' tensile strength and modulus of elasticity were enhanced after being treated with alkali [46]. This was due to the removal of lignin and hemicellulose via the treatment, which increased the fibres' roughness and effective surface area. It was reported that the tensile strength of alkali-treated bamboo fibres improved compared to that of untreated bamboo fibres [46]. In addition, sisal fibres with the alkaline treatment had the highest tensile strength, with 12% higher tensile strength than that of untreated sisal fibres, which agrees with the finding that the removal of hemicellulose and a portion of lignin increased the interfacial adhesion between the treated fibres and the matrix [47].

Alkaline treatment improved the surface roughness of kenaf fibres and increased mechanical interlocking, which concurs with the findings from a previous study [48]. Alkali-treated jute fibres showed enhanced tensile and flexural strength and did not affect impact and fatigue behaviours [49]. It can be concluded that different treatment procedures of natural fibres affected fibre length, volume percentage, and orientation in different manners [50].

TABLE 3 shows the result of optimal tensile strength with various alkali concentrations for five different fibres. It was discovered that the alkaline treatment of natural fibres is the most extensively applied and the most versatile method to significantly improve tensile strength. However, the concentration of NaOH, treatment periods, and treatment temperature may influence fibre effectiveness in terms of tensile strength.

TABLE 3

Effect of Alkaline Treatment on Tensile Strength

Type of fibre	Alkaline concentration (%)	Tensile Strength (MPa)	Reference
Bamboo	10	368.33	[46]
Sisal	3	55.02	[47]
Kenaf	1	396	[48]
Jute	5	393-800	[49]
Banana	1	443	[50]

5. Conclusion

In summary, kenaf fibres had the minimum lignin content, which was 2.39%, and cotton fibres had the greatest lignin at 16%. On the other hand, cotton fibres had the minimum hemicellulose at 1% to 3% and hemp had the maximum hemicellulose content at 17.9% to 22.4%. Therefore, kenaf fibres had the overall minimum cellulose, lignin, and hemicellulose. Furthermore, based on the effect of moisture content on tensile strength, it can be concluded that sisal fibres had the highest tensile strength at 680 MPa with 65% moisture content, while the least was at 20% for bamboo fibres with tensile strength of 231 MPa. In addition, sisal fibres with alkaline treatment had the highest tensile strength, with 12% higher tensile strength than that of untreated sisal fibres, where the removal of hemicellulose and a portion of the lignin increased the interfacial adhesion between the treated fibres and the matrix.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot H801).

REFERENCES

[1] A. Stuart-Street, N.S. Dr, P. Galloway, N.R. Schoknecht, A Simple Guide for Describing Soil, Department of Primary Industries and Regional Development, June 2020.

[2] I.Y. Salena, A Case Study of Foundation Failure in the Existing Residential Building, Jurnal Teknik Sipil Fakultas Teknik. **4** (2), 91-103 (2016). DOI: https://doi.org/10.35308/jts-utu.v2i1.340

[3] Y. Yuriz, T.N.H. Tuan Ismail, N. N. Mat Hassan, An Overview of Waste Materials for Sustainable Road Construction. Sustain Dev. **11** (1), 215-229 (2020). DOI: https://doi.org/10.30880/ijscet.2020.11.01.021

[4] R. Ramkrishnan, M.R. Sruthy, A. Sharma, V. Karthik, Effect of Random Inclusion of Sisal Fibres on Strength Behavior and Slope Stability of Fine Grained Soils, Mater Today-Proc. **5** (11), 25313-25322 (2018). DOI: https://doi.org/10.1016/j.matpr.2018.10.334

[5] K.S. Kulhar, M. Raisinghani, Engineering Performance Review of Soil Reinforcement with Natural Fibers, Journal of Civil Engineering and Environmental Technology **5** (1), 20-26 (2018).

[6] V.K. Shrivastava, A review: Sisal Fibre Behavior As Reinforcement in Composites, Journal of Basic and Applied Engineering Research. **4** (2), 172-175 (2017).

[7] R. Dungani, M. Karina, Subyakto, A. Sulaeman, D. Hermawan, A. Hadiyane, Agricultural Waste Fibers Towards Sustainability and Advanced Utilization: A review, Plant Sci. **15** (1-2), 42-55. DOI: https://doi.org/10.3923/ajps.2016.42.55

[8] N. Ramli, N. Mazlan, Y. Ando, Z. Leman, K. Abdan, A.A. Aziz, N.A. Sairy, Natural Fiber for Green Technology in Automotive Industry: A Brief Review, IOP Conference Series: Materials Science and Engineering **368** (1), 012012 (2018). DOI: https://doi.org/10.1088/1757-899X/368/1/012012

[9] F.X. Espinach, Advances in Natural Fibers and Polymers, Materials **14** (10), 2607 (2021). DOI: https://doi.org/10.3390/ma14102607

[10] T. Khan, M.T. Hameed Sultan, A.H. Ariffin, The Challenges of Natural Fiber in Manufacturing, Material Selection, and Technology Application: A Review, Reinforced Plastics and Composites **37** (11), 770-779 (2018). DOI: https://doi.org/10.1177/0731684418756762

[11] A. Gholampour, T.A. Ozbakkaloglu, Review of Natural Fiber Composites: Properties, Modification and Processing Techniques, Characterization, Applications. Mater Sci. **55**, 829-892 (2020). DOI: https://doi.org/10.1007/s10853-019-03990-y

[12] A. Darwis, A.H. Iswanto, Morphological Characteristics of Bambusa Vulgaris and The Distribution and Shape of Vascular Bundles Therein, Korean Wood Sci. Technol. **46** (4), 315-322 (2018). DOI: https://doi.org/10.5658/WOOD.2018.46.4.315

[13] A. Rochim, K. Latifah, B. Supriyadi, Characterization of Compression and Tensile Properties of Bamboo Jawa (Gigantochloa Atter) and Bamboo Apus (Gigantochloa Apus) for Application as Soil Reinforcement,, IOP Conference Series: Earth and Environmental Science **498** (1), 012040 (2020). DOI: https://doi.org/10.1088/1755-1315/498/1/012040

[14] C. Tezara, J.P. Siregar, H.Y. Lim, F.A. Fauzi, M.H. Yazdi, I.K. Moey, J.W. Lim, Factors That Affect The Mechanical Properties of Kenaf Fiber Reinforced Polymer: A Review, Mech. Eng. Sci. **10** (2), 2159-2175 (2016). DOI: https://doi.org/10.15282/jmes.10.2.2016.19.0203

[15] S. Sathees Kumar, R. Muthalagu, C.H. Nithin Chakravarthy, Effects of Fiber Loading on Mechanical Characterization of Pineapple Leaf and Sisal Fibers Reinforced Polyester Composites for Various Applications,, Mater. Today-Proc. **44** (1), 546-553 (2021). DOI: https://doi.org/10.1016/j.matpr.2020.10.214

[16] F. Jahan, M. Soni, Effects of Chemical Treatment on Mechanical Properties of Various Natural Fiber Reinforced Composite: A Review, Mater. Today-Proc. **46** (15), 6708-6711 (2021). DOI: https://doi.org/10.1016/j.matpr.2021.04.175

[17] D.S. Vijayan, D. Parthiban, Effect of Solid Waste Based Stabilizing Material for Strengthening of Expansive Soil – A Review, Environmental Technology and Innovation **20**, 101108 (2020). DOI: https://doi.org/10.1016/j.eti.2020.101108

[18] C. Mizera, D. Herak, P. Hrabe, A. Kabutey, Effect of Temperature and Moisture Content on Tensile Behaviour of False Banana Fibre (Ensete Ventricosum), Int. Agrophys. **31** (3), 377-382 (2017). DOI: https://doi.org/10.1515/intag-2016-0067

[19] N. Razali, M.S. Salit, M. Jawaid, M.R. Ishak, Y. Lazim, A Study on Chemical Composition, Physical, Tensile, Morphological, and Thermal Properties of Roselle Fibre: Effect of Fibre Maturity, Bioresources **10**, 1803-1823 (2015).

[20] H. Chen, J. Wu, J. Shi, W. Zhang, H. Wang, Effect of Alkali Treatment on Microstructure and Thermal Stability of Parenchyma Cell Compared with Bamboo Fiber, Ind. Crop. Prod. **164**, 113380 (2021). DOI: https://doi.org/10.1016/j.indcrop.2021.113380

[21] A.A. Salih, R. Zulkifli, C.H. Azhari, Tensile Properties and Microstructure of Alkali Treatment, Fibers **8** (5), 26 (2020). DOI: https://doi.org/10.3390/fib8050026

[22] J.A. Lolo, S. Nikmatin, H. Alatas, D.D. Prastyo, A. Syafiuddin, Fabrication of Biocomposites Reinforced with Natural Fibers and Evaluation of Their Physio-Chemical Properties, Biointerface Research in Applied Chemistry **10** (4), 5803-5808 (2020). DOI: https://doi.org/10.33263/BRIAC104.803808

[23] J. Naveen, M. Jawaid, P. Amuthakkannan, M. Chandrasekar, Mechanical and Physical Properties of Sisal and Hybrid Sisal Fiber-Reinforced Polymer Composites, Woodhead Publishing Series in Composites Science and Engineering **426-440** (2019). DOI: https://doi.org/10.1016/B978-0-08-102292-4.00021-7

[24] D.B. Guido, F. Vincenzo, V. Antonino, Natural Fibre Reinforced Composites, Mater. Sci. Tech. Ser. 57-90 (2012).

[25] K. Senthilkumar, I. Siva, N. Rajini, J.T.W. Jappes, S. Siengchin, Mechanical Characteristics of Tri-Layer Eco-Friendly Polymer Composites for Interior Parts of Aerospace Application, Woodhead Publishing Series in Composites Science and Engineering 35-53 (2018). DOI: https://doi.org/10.1016/B978-0-08-102131-6.00003-7

[26] Sagar Chokshi, Vijay Parmar, Piyush Gohil, Vijaykumar Chaudhary, Chemical Composition and Mechanical Properties of Natural Fibers, Natural Fibers **19** (10), 3942-3953 (2020). DOI: https://doi.org/10.1080/15440478.2020.1848738

[27] A.L. Mohamed, A.G. Hassabo, Flame Retardant of Cellulosic Materials and Their Composites, Flame Retardants 247-314 (2015). DOI: https://doi.org/10.1007/978-3-319-03467-6_10

[28] S. Zhang, B. Fei, Y. Yu, H. Cheng, C. Wang, Effect of the Amount of Lignin on Tensile Properties of Single Wood Fibers, Forest Science and Practice **15**, 56-60 (2013). DOI: https://doi.org/10.1007/s11632-013-0106-0

[29] M. Liu, A.S. Meyer, D. Fernando, D.A.S. Silva, G. Daniel, A. Thygesen, Effect of Pectin and Hemicellulose Removal from Hemp Fibres on the Mechanical Properties of Unidirectional Hemp/Epoxy Composites, Compos. Part A – Appl. S. **90**, 724-735 (2016). DOI: https://doi.org/10.1016/j.compositesa.2016.08.037

[30] Z. Yang, H. Peng, W. Wang, T. Liu, Crystallization Behavior of Poly(E-Caprolactone)/Layered Double Hydroxide Nanocomposites, Applied Polymer Science **116** (5), 2658-2667 (2010). DOI: https://doi.org/10.1002/app.31787

[31] J. Chen, K. Wang, F. Xu, R. Sun, Effect of Hemicellulose Removal on the Structural and Mechanical Properties of Regenerated Fibers from Bamboo', Cellulose **22** (1), 63-72 (2015).
DOI: https://doi.org/10.1007/s10570-014-0488-8

[32] A. Khosro, M.R.S. Shadbad, A. Nokhodchi, A. Javadzedeh, M. Barzegar-Jalali, J. Barar, G. Mohammadi, Y. Omidi, Piroxicam Nanoparticles for Ocular Delivery: Physicochemical Characterization and Implementation in Endotoxin-Induced Uveitis, Drug Targeting **15** (6), 407-416 (2008).
DOI: https://doi.org/10.1080/10611860701453125

[33] G.L. Sivakumar Babu, A.K. Vasudevan, Strength and Stiffness Response of Coir Fiber-Reinforced Tropical Soil, Materials in Civil Engineering **20** (9), 571-577 (2008).
DOI: https://doi.org/10.1061/(ASCE)0899-1561(2008)20:9(571)

[34] I. Chang, J. Im, G.-C. Cho, Introduction of Microbial Biopolymers in Soil Treatment for Future Environmentally-Friendly and Sustainable Geotechnical Engineering, Sustainability-Basel. **8** (3), 251 (2016).
DOI: https://doi.org/10.3390/su8030251

[35] T. Zhang, S. Liu, G. Cai, A.J. Puppala, Experimental Investigation of Thermal and Mechanical Properties of Lignin Treated Silt, Eng Geol. **196**, 1-11 (2015).
DOI: https://doi.org/10.1016/j.enggeo.2015.07.003

[36] H. Wang, G. Tian, W. Li, D. Ren, X. Zhang, Y. Yu, Sensitivity of Bamboo Fiber Longitudinal Tensile Properties to Moisture Content Variation Under The Fiber Saturation Point, Wood Sci. **61** (3), 262-269 (2015).
DOI: https://doi.org/10.1007/s10086-015-1466-y

[37] E. Muñoz, J.A. García-Manrique, Water Absorption Behaviour and Its Effect on The Mechanical Properties of Flax Fibre Reinforced Bioepoxy Composites, Polymer Science (2015).
DOI: http://dx.doi.org/10.1155/2015/390275

[38] A.D. Gudayu, L. Steuernagel, D. Meiners, R. Gideon, Effect of Surface Treatment on Moisture Absorption, Thermal, and Mechanical Properties of Sisal Fiber, Industrial Textiles **51** (2), 2853S-2873S.
DOI: https://doi.org/10.1177/1528083720924774

[39] D. Awalluddin, M.A. Mohd Ariffin, M.H. Osman, M.W. Hussin, M.A. Ismail, H. Lee, N.H. Abdul Shukor Lim, Mechanical Properties of Different Bamboo Species. International Conference of Euro Asia Civil Engineering Forum **138**, 01024 (2017).
DOI: https://doi.org/10.1051/matecconf/201713801024

[40] M.C. Symington, W.M. Banks, O.D. West, R.A. Pethrick, Tensile Testing of Cellulose Based Natural Fibers for Structural Composite Applications, Composite Materials **43** (9), 1083-1108 (2009).
DOI: https://doi.org/10.1177/0021998308097740

[41] L. Prabhu, V. Krishnaraj, S. Sathish, S. Gokulkumar, N. Karthi, L. Rajeshkumar, D. Balaji, N. Vigneshkumar, K.S. Elango, A Review on Natural Fiber Reinforced Hybrid Composites: Chemical Treatments, Manufacturing Methods and Potential Applications, Mater. Today-Proc. **45** (9), 8080-8085 (2021).
DOI: https://doi.org/10.1016/j.matpr.2021.01.280

[42] X. Yang, K. Wang, G.T., X. Liu, S. Yang, Evaluation of Chemical Treatments to Tensile Properties of Cellulosic Bamboo Fibers, Wood Wood Prod. **76** (4), 1303-1310 (2018).
DOI: https://doi.org/10.1007/s00107-018-1303-2

[43] Mukesh, S.S. Godara, Effect of Chemical Modification of Fiber Surface on Natural Fiber Composites: A Review', Mater. Today-Proc. **18** (7) 3428-3434 (2019).
DOI: https://doi.org/10.1016/j.matpr.2019.07.270

[44] M.H. Zin, K. Abdan, N. Mazlan, E.S. Zainudin, K.E. Liew, The Effects Of Alkali Treatment on The Mechanical and Chemical Properties of Pineapple Leaf Fibres (PALF) and ADHESION TO EPOXY RESIN', IOP Conference Series: Materials Science and Engineering **368** (1), 012035.
DOI: https://doi.org/10.1088/1757-899X/368/1/012035

[45] Y. Shireesha, G. Nandipati, State of Art Review on Natural Fibers, Mater. Today-Proc. **18** (1), 15-24 (2019).
DOI: https://doi.org/10.1016/j.matpr.2019.06.272

[46] F.S. Tong, S.C. Chin, M.T. Mustafa, H.R. Ong, M.M.R. Khan, J. Gimbun, S.I. Doh, Influence of Alkali Treatment on Physico-Chemical Properties of Malaysian Bamboo Fiber: A Preliminary Study, Anal. Sci. **22** (1), 143-150 (2018).
DOI: https://doi.org/10.17576/mjas-2018-2201-18

[47] P.S. Kumar, S. Prakash, J. Prakash, The Effect of Chemical Treatment on The Tensile Properties of Sisal Fibre Reinforced Epoxy Composite', Engineering and Technology **5** (8), 1431-1435 (2018).
DOI: https://www.irjet.net/archives/V5/i8/IRJET-V5I8245.pdf

[48] R. Ahmad, R. Hamid, S.A. Osman, Effect of Fibre Treatment on the Physical and Mechanical Properties of Kenaf Fibre Reinforced Blended Cementitious Composites, Civil Engineering **23** (9), 4022-4035 (2019).
DOI: https://doi.org/10.1007/s12205-019-1535-7

[49] B. Koohestani, A.K. Darban, P. Mokhtari, E. Yilmaz, E. Darezereshki, Comparison of Different Natural Fiber Treatments: A Literature Review, Environmental Science and Technology **16** (1), 629-642 (2019).
DOI: https://doi.org/10.1007/s13762-018-1890-9

[50] U.S. Gupta, M. Dhamarikar, A. Dharkar, S. Chaturvedi, S. Tiwari, R. Namdeo, Surface Modification of Banana Fiber: A Review, Mater Today-Proc. **43** (2), 904-915 (2021).
DOI: https://doi.org/10.1016/j.matpr.2020.07.217